DEVELOPMENT OF THE SELF MAGNETIC PINCH DIODE AS A HIGH BRIGHTNESS RADIOGRAPHIC SOURCE

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Abstract

The Self Magnetic Pinch (SMP) diode has been developed from a low voltage (<2MV) to a high voltage (7-8MV) radiographic source as part of a program to build a Hydrodynamics research facility (Hydrus) at AWE Aldermaston.

Development of the initial AWE diode design has used the facilities and assistance of a number of UK and US laboratories and companies to carry out both experimental and theoretical investigations into the operation of the diode. Experimental campaigns have been carried out to both investigate the physics operation and to demonstrate performance on the RITS-3 and RITS-6 drivers at SNL, the Mercury and Gamble II drivers at NRL and the Mogul D and EROS drivers at AWE. Modelling of the diode has been carried out mainly using the Particle in Cell (PiC) code LsP.

It has been demonstrated that the diode has achieved the required radiographic performance for Hydrus and it will be used as the initial operational diode when the facility is commissioned. Research to develop a long term diode with improved performance is still continuing..

A. INTRODUCTION

The Atomic Weapons Establishment (AWE) Aldermaston currently use flash radiography as a diagnostic for hydrodynamics experiments. A project is under way to improve the existing radiographic experimental facilities. This includes new multi-megavolt Pulsed Power drivers and diodes producing high intensity (hundreds of Rads at 1m), short duration (<100ns) pulses of radiation from small diameter (<2mm) sources.

Previous work had been done to establish radiographic requirements for these diodes [1]. The requirements have been stated in terms of output dose (in Rad at 1m) and radiographic source diameter (in mm). Two stages of requirements have been developed, day requirements which will be available for the commissioning of the facility and long term requirements which will be available for a future upgrade to the facility. The day 1 requirements have been further divided into Scaled and Full Scale experimental needs. The requirements are:

a. Day 1, scaled: 250 Rads at 1m, <2.75mm
b. Day 1, full scale: 600 Rads at 1m, <5mm
c. Long term: 1000 Rads at 1m, <2mm.

The SMP diode has already been chosen to be used as the day 1 diode for both scaled and full scale experiments.

This paper describes the program of work which has taken place to inform that decision.

B. HIGH VOLTAGE OPERATION

The SMP diode has been used for a low voltage (<2MV) radiographic source for

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14. ABSTRACT
The Self Magnetic Pinch (SMP) diode has been developed from a low voltage (<2MV) to a high voltage (7-8MV) radiographic source as part of a program to build a Hydrodynamics research facility (Hydrus) at AWE Aldermaston. Development of the initial AWE diode design has used the facilities and assistance of a number of UK and US laboratories and companies to carry out both experimental and theoretical investigations into the operation of the diode. Experimental campaigns have been carried out to both investigate the physics operation and to demonstrate performance on the RITS-3 and RITS-6 drivers at SNL, the Mercury and Gamble II drivers at NRL and the Mogul D and EROS drivers at AWE. Modelling of the diode has been carried out mainly using the Particle in Cell (PiC) code LsP. It has been demonstrated that the diode has achieved the required radiographic performance for Hydrus and it will be used as the initial operational diode when the facility is commissioned. Research to develop a long term diode with improved performance is still continuing..

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approximately 30 years at AWE on the Mevex and Mini-B drivers. Initial work in the program was based around demonstrating the diode operation at higher voltages. This began on the Single Pulse Forming Line (SPFL) machine Mogul D at AWE [2]. The envisaged pulsed power driver for use in the Hydrus facility is an Inductive Voltage Adder (IVA) (Figure 1).

Figure 1. Proposed AWE Hydrus IVA machine

As high voltage IVA drivers became available for use in the US, initially the RITS-3 (4-5MV) machine at SNL [3] and later the Mercury (6MV) machine at NRL [4]. The diode was tested on these drivers [5]. It proved to transfer to IVA drivers at higher voltage successfully, requiring only minor geometric changes to optimise its performance. Most recent high voltage demonstration shots have taken place on the upgraded SNL RITS-6 machine [6] at approximately 6.3MV where the diode produced 370Rad at 1m with a 2.7mm source diameter [7].

C. PHYSICS INVESTIGATIONS

Investigations into the physics of the diode have been based in two areas:

a. Pinch physics – what causes the electron beam to pinch and how is this dependant upon the diode geometry and materials.
b. Characterisation of plasmas created within the AK gap.

a. Pinch Physics

These investigations have taken place on the SNL RITS-3 driver and the AWE EROS driver.

The first stage of the work was to image the source to obtain its time resolved history. The SNL developed TRSD and AWE developed NSGC diagnostics were used to obtain this information [8]. The two systems complement each other with the TRSD producing one dimensional source diameter information streaked in time throughout the radiation pulse and the NSGC giving two dimensional source diameter information at discreet time intervals. Between both systems, a time resolved history of the diode source diameter was achieved (Figure 2).

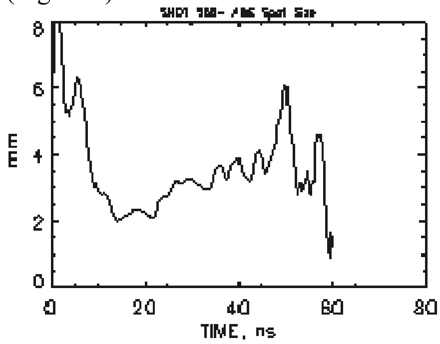


Figure 2. Time resolved history of SMP source diameter.

This showed the diode to pinch to a small diameter within 10 – 15ns, it then remained at a small size until the pulsed power drive fell off, at which time the diameter began to grow.

The second stage of the work was then to investigate how the geometry and materials used within the anode assembly affected the pinch. This work took place on the EROS driver at AWE [9]

A number of experiments took place in which the relative positions and dimensions of the foil and high Z converter target were varied. A lot of information concerned with the diode electrical behaviour (impedance) and radiographic performance (output dose, source diameter and uniformity) was gathered. It can be summarised by stating that the diode impedance and pinch behaviour appeared to be dominated by the thin aluminium foil positioned in front of the converter target. Good impedance and pinch behaviour took place as long as the foil was present.

b. Plasma Investigations

Expanding plasma within the anode cathode gap of the diode has historically been considered to be the mechanism which caused the diode to fail (characterised by collapsing impedance and low radiographic performance). A great deal of work has been carried out on a variety of drivers (RITS-3 and RITS-6 at SNL, Mercury at NRL and EROS at AWE) attempting to characterise the expanding plasmas. The work has been carried out in different phases.

Optical imaging of the plasma using both focussed fibre optics and with framing cameras to determine the source of the plasmas and their time evolution. (Figure 3)

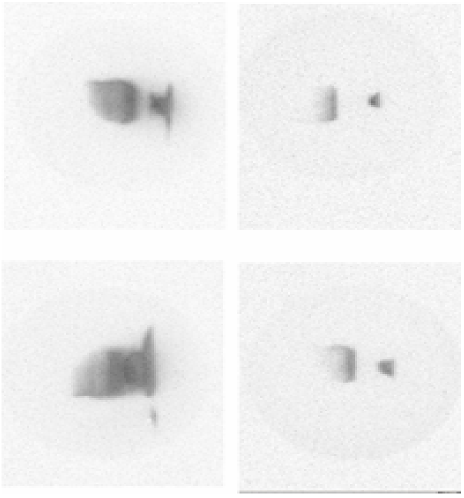


Figure 3. Optical imaging of plasma evolution from SMP diode

This technique, however, diagnoses only the visible light from the plasma and gives no information on its density, temperature or constituents. Interferometry techniques were used to attempt to interrogate the plasma density and expansion velocity [10] (Figure 4).

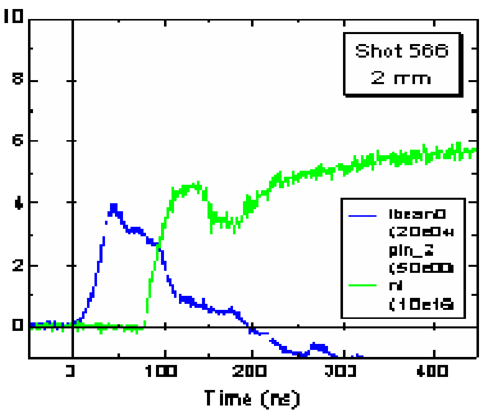


Figure 4. Plot showing interferometry derived plasma density and time of arrival.

More recently spectroscopy has been used to identify the plasma constituents [11] (Figure 5).

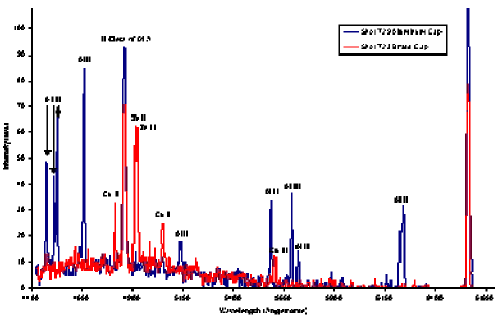


Figure 5. Typical spectroscopy results showing discreet emission lines

It is thought that spectroscopy will also allow further information to be gained on the temperature and density of the plasma through the relative intensities of the emission lines as well as their broadening.

D. THEORY INVESTIGATIONS

Modelling work has been carried out using Particle in Cell (PiC) and hydrodynamic codes to compare simulation to experimental results. Basic models of the SMP diode using the PiC code LsP [12] have been developed with the inclusion of more realistic physics phenomena. Older models used simple temperature dependant thresholds to allow positive ions to be created within the anode-cathode gap whereas more recent versions have included the desorption of neutrals which are allowed to be ionised by the electron beam [13]. Improved plasma expansion methods are also being developed for inclusion into the diode model [13] (Figure 6).

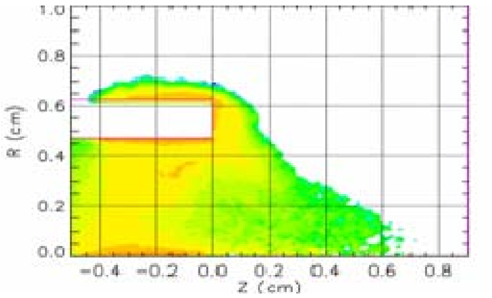


Figure 6. Simulation of expanding plasma within SMP diode.

The improved diode modelling has required the development of improved post processing and data visualisation methods (Figure 7).

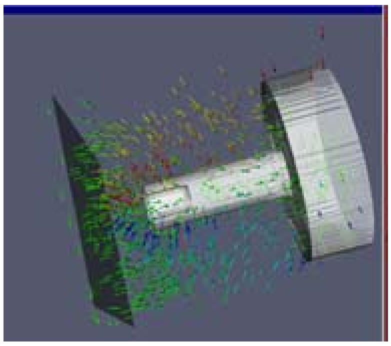
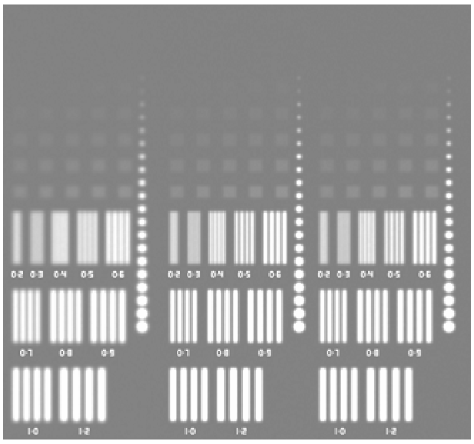


Figure 8. Visualisation of electro flow within diode

E. RADIOGRAPHIC PERFORMANCE PREDICTION

AWE routinely use the Los Alomos developed Bayseian Inference Engine (BIE) code to forward model predicted radiographs. Improvements have been made to this code to allow the inclusion of a variety of line spread functions to more realistically model the radiographic source. Experimentally demonstrated radiographic sources as well as predicted ones have been used to predict the likely quality of radiographs that would be produced by the SMP diode within the Hydrus facility. The predicted radiographs also include best estimates for detector efficiencies and blurs as well as scatter backgrounds. Figure 8 shows predicted radiographs for three radiographic sources:

a. The Hydrus required 14MeV, 600R, 5mm source
b. A prediction of the SMP diode performance on the Hydrus IVA driver. 8MeV, 500R, 2.75mm.
c. A demonstrated 7MeV, 375R, 2.75mm source.



(a) b) (c)

Figure 8. Predicted radiograph using SMP diode with different performance sources

The predicted radiograph contains three types of test objects, tiles of different thickness, line pairs with different separations and holes of different diameters. Analysis of the radiograph shows that the even the lower performance 375R, 2.75mm source has equivalent radiographic performance as the required Hydrus source and the 500R, 2.75mm source exceeds the quality of the Hydrus required source.

H. CONCLUSIONS

As a result of a collaborative research program involving a number of US laboratories and companies, the SMP diode has been developed from a low voltage, low aerial mass radiographic source to one that is capable of both scaled and full scale core punch radiography.

Performance of 350 – 400Rad@1m with a 2.7mm AWE definition spot size have been demonstrated at 6.3MV with performance predicted to improve to approximately 450 – 500 Rad@1m with a 2.5mm AWE definition spot size on the Hydrus IVA machine.

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